

## **Do nest boxes in restored woodlands promote the conservation of hollow-dependent fauna?**

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**Running title:** Nest box use in woodlands

## **Abstract**

Vegetation restoration is considered an important strategy for reversing biodiversity decline in agricultural areas. However, revegetated areas often lack key vegetation attributes like large old hollow-bearing trees. As these trees take a long time to develop, artificial cavities such as nest boxes are sometimes provided to address lag effects. We conducted a 3-year experiment using 150 nest boxes with four designs to quantify patterns of occupancy within 16 replanted areas and 14 patches of remnant old growth eucalypt woodland. We quantified patterns of occupancy of nest boxes in physically connected versus isolated remnants and plantings, and multiple covariate effects on nest box occupancy at the nest box, tree, patch and landscape levels. Our analyses revealed a lower probability of nest box occupancy within remnants (versus plantings) for two of the six response variables examined: any species, and the Feral Honeybee. Nest boxes in connected remnants and plantings were more likely to be occupied than those in isolated plantings and remnants by any mammal and the Common Brushtail Possum. Nest boxes in restored woodlands are used by some hollow-dependent fauna, but principally already common species, and not taxa of conservation concern. Nest boxes also were used by pest species. A key management consideration must be to create connected habitat to facilitate colonization of nest boxes by mammals. Approximately 15% of the cavity-dependent vertebrates within the study area used nest boxes, possibly because the diverse requirements of the array of other species were not met by the range of nest boxes deployed.

**Keywords:** Cavity-users, connectivity, hollow-dependent animals, large old trees, vegetation restoration, agricultural landscapes

### **Implications for Practice**

- Restored areas often lack key attributes that are critical for biodiversity. Large old trees with hollows are one of these key attributes.
- The establishment of nest boxes within revegetated areas is one potential practical strategy to promote colonization by cavity-dependent wildlife.
- The connectedness of sites influenced nest box occupancy and appears to be important for improving the effectiveness of nest box programs, particularly for some species of arboreal marsupials.
- Nest boxes primarily benefitted already common species or pest species. Taxa of conservation concern may require highly targeted species-specific nest box designs and/or prolonged periods of time to colonize nest boxes.

### **Introduction**

Millions of hectares of land worldwide are in need of restoration (Clewett & Aronson 2007; Minnemeyer et al. 2011; Menz et al. 2013; Suding et al. 2015), particularly in agricultural areas where extensive native vegetation clearing has led to a wide range of environmental problems including land degradation and biodiversity loss (Karp et al. 2012; Loos et al. 2014; Latawiec et al. 2015). Vegetation restoration is considered to be an important strategy for reversing biodiversity decline in agricultural areas (e.g. Bullock et al. 2011; Cristescu et al. 2012). However, the effectiveness of restoration for biodiversity still needs to be carefully quantified (e.g. Ray Benayas et al. 2009; Catterall et al. 2012; Wortley et al. 2013). Indeed, revegetated areas often lack key attributes of vegetation structure like large old hollow-bearing trees that take a long time to develop (Vesk et al. 2008) and which provide crucial habitat structures that biota depend on for survival (e.g. hollows, fallen woody debris, and decorticated bark microhabitat) (Gibbons et al. 2008; Fischer et al. 2010; Crane et al. 2014).

A paucity of these key resources may mean that a significant proportion of the fauna that might otherwise inhabit areas of natural vegetation in agricultural areas will be absent (Flaquer et al. 2006; Cunningham et al. 2007). The provision of artificial cavities such as nest boxes is one widely employed approach that attempts to address this problem of lag effects in the time needed to recruit large old hollow-bearing trees (Beyer & Goldingay 2006; Goldingay & Stevens 2009) including in restored areas in agricultural landscapes (Goldingay et al. 2015). To date there is limited information on the effectiveness of nest boxes in recovering biodiversity in restored areas.

In this study, we quantified patterns of occupancy of nest boxes within replanted areas and compared them with matched patches of remnant old growth temperate eucalypt woodland (sensu Lindenmayer et al. 2012). We focused our study on the temperate woodland biome of the South West Slopes of New South Wales, south-eastern Australia. We posed the key question: *Are there differences in nest box occupancy between woodland remnants and plantings?* At the outset of this study, we postulated that rates of occupancy would be significantly higher in nest boxes established within plantings than in remnants. This was because previous studies in other vegetation types such as forests and plantations (see Smith & Agnew 2002; Lindenmayer et al. 2009) have found that hollow-dependent animals are less likely to use nest boxes when natural cavities are more readily available (as occurs in this study within woodland remnants that are dominated by large old trees).

Vegetation cover in many agricultural landscapes (including in our study area) has been extensively cleared and fragmented (Gibbons & Boak 2002). As a result, areas of both remnant native woodland and replantings are often physically disconnected from other areas of native vegetation. This may, in turn, affect movement and hence patch occupancy patterns by a range of fauna, including hollow-dependent taxa that might otherwise potentially use nest boxes (Cooper et al. 2002; van der Ree et al. 2004; Doerr et al. 2010). On this basis, a

key additional question in our investigation was: *Are there differences in the occupancy of nest boxes among remnants and plantings that are physically connected to other areas of native vegetation versus those which are isolated?* At the outset of this investigation, we postulated that such differences in physical connectivity (sensu Lindenmayer & Fischer 2006) would influence nest box occupancy for dispersal-limited species such as arboreal marsupials, but not for more mobile taxa like the majority of birds and invertebrates such as the Feral Honeybee (*Apis mellifera*).

We also sought to determine if there was an interaction between broad vegetation type and connectedness effects. That is: *Are there differences in occupancy rates of nest boxes between connected and unconnected plantings versus those in connected and unconnected remnants?* If both design variables (viz: broad vegetation type and connectedness) are important, then the highest rates of nest box occupancy would be predicted to occur in connected plantings and the lowest in unconnected remnants.

In addition to addressing the three questions outlined above, we also quantified the effects of other covariates at box, site and landscape-level. These included the entrance type and other physical characteristics of nest boxes, density of stems at a site, distance of a site (i.e. a remnant or planting) to a watercourse, and the number of large old scattered paddock trees in the landscape surrounding a given site. A paddock tree was defined as a scattered tree in an otherwise cleared or semi-cleared agricultural field (or paddock) (sensu Manning et al. 2006). We explored the effects of these covariates as they have been found to be important in other studies of nest boxes (e.g. Finch 1989; Fargallo et al. 2001; Smith & Agnew 2002; Durant et al. 2009; Goldingay & Stevens 2009; Goldingay et al. 2015).

Nest boxes are a widely recommended management activity for restored areas of temperate woodland in many parts of Australia. Our hope is that the new information

presented in this paper will assist closing key knowledge gaps associated with the twin goals of vegetation and wildlife restoration in Australian agricultural landscapes.

## Methods

### *Study area and study design*

We conducted this study in the Junee district of southern New South Wales, south-eastern Australia (Figure 1). The district is highly modified for agriculture and the majority of the former cover of native vegetation has been cleared to make way for dryland cropping and for grazing livestock. The remaining native vegetation occurs predominately along roadsides, within riparian zones, as small patches of paddock trees or as scattered paddock trees (Crane et al. 2014). Over the last 30 years farmers have been attempting to address the lack of native vegetation by establishing native vegetation plantings.

Our study encompassed 150 nest boxes located on 30 sites each with 5 nest boxes of different designs. The 30 sites comprised seven connected plantings, nine isolated plantings, eight connected remnants and six isolated remnants. We classified sites as isolated if there was a gap  $> 70\text{m}$  to an area of native vegetation. This value was based on previous studies that have indicated that gaps in native vegetation can significantly impede movement of animals such as arboreal marsupials. This is because gliding marsupials are unable to volplane between widely spaced trees (van der Ree et al. 2004) – especially in woodlands and plantings where tree height is limited to 30 m (and often much shorter) which limits gliding distance (as it is a function of tree height; Lindenmayer 2002).

The plantings in our study were typically 15-25 years old, with tree heights 12-15 m tall. Plantings were characterized by a mix of locally endemic and exotic Australian ground cover, understorey and overstorey plant species (primarily *Eucalyptus* and *Acacia* spp). Most plants were typically spaced 2 m apart, but there was not a standard set of spacing and plant species composition protocols applied in revegetation efforts. There was an average of 0.15

hollow-bearing trees per ha in the plantings. The remnant patches in our study were dominated by Box-gum woodlands and occurred along roadsides and as small patches of trees in an otherwise highly modified cropping or grazing paddocks. There was an average of 2.11 hollow-bearing trees per ha in the remnants.

We erected nest boxes in February 2010. At each site, we attached nest boxes to living and dead trees between 3 and 6 metres above the ground. We deployed four different box designs (see Table S1) that were based on designs previously used to accommodate particular species, the Common Brushtail Possum (*Trichosurus vulpecula*), Squirrel Glider (*Petaurus norfolcensis*), the Superb Parrot (*Polytelis swainsonii*) and the Laughing Kookaburra (*Dacelo novaeguineae*). We modified the glider and kookaburra boxes by adding a 30mm cavity in the back wall as an experimental bat chamber. The nest boxes were constructed from marine plywood. We installed nest boxes within 200m of each other and at each site supported one Common Brushtail Possum (BP) box, two Squirrel Glider (SG) boxes, one Superb Parrot (SP) box and one Laughing Kookaburra (KB) box or two BP boxes, two SG boxes, and one SP box.

We checked nest boxes on four occasions: October (spring) 2010, December/January (summer) 2010/11, October (spring) 2011 and December/January (summer) 2012/13. These periods corresponded to times when many cavity-dependent animals are breeding and there is a high chance of detecting them. We determined usage from the presence of an animal, scats, hairs, feathers, nest, eggs or a combination of methods. In the absence of an animal, species identify was determined through scat or hair analysis by an expert (Barbara Triggs) who assigned a level of confidence to each record (definite, probable or uncertain). We restricted our analyses to data on animals that were physically observed and scat and fur samples deemed to be “definite”.

We measured finescale covariates in the field and calculated broadscale covariates from spatial data layers in a GIS for subsequent use in modeling of the factors influencing nest box occupancy. We explored these two scales of variables because choices by land managers about locating nest boxes can often be made at both a broadscale (e.g. which farms) and at finescale (e.g. which patch and which tree within patch).

Finescale variables were attributes of a given nest box, tree (as an attachment site) or site within which nest boxes were established and they included the diameter of tree on which a nest box was attached, the level of dieback of the tree on which the nest box was attached, the total number of stems at a site, the number of trees greater than 50 cm in diameter at a site, number of hollow bearing trees at a site and a lithology fertility rating.

Broadscale variables characterized the landscape surrounding locations where nest boxes were established and they included the number of paddock trees within 500 m of the site, the distance from a site to a drainage line, topographic wetness index (TWI), and the distance to the closest major patch of native vegetation. The topographic wetness index is a continuous terrain-based measure of likely moisture contributed to a site as a result of an area's position in the landscape, ranging from negative values on ridges (with no contributing catchment) and upper slopes (small contributing catchment/steep slope) to increasingly higher positive values through lower slopes, valley flats and eventually drainage lines.

### **Statistical analyses**

We grouped the species recorded in the nest boxes into five broad overlapping categories. Specifically, we analyzed the presence in the nest boxes of the following groups: marsupials (Antechinus, Common Brushtail Possum, Common Ringtail Possum, Sugar Glider), mammals (marsupials plus the Lesser Long-eared Bat and the exotic Black Rat), birds (Cockatiel, Common Starling, Eastern Rosella and Galah), other species – non-mammal or bird (Feral Honeybees, Peron's Tree Frog and Marbled Gecko) and any species detected. We



also modeled the three individual species with sufficient presence data to warrant further individual analysis (Common Brushtail Possum, Common Starling and Feral Honeybees).

We modeled the effects of four broadscale or finescale (site-level) variables and one interaction: survey occasion (spring 2010, spring 2011, summer 2011 and spring 2012); connectivity (connected and isolated); vegetation type (planting versus remnant); Number of paddock trees within 500 meters; and the interaction between connectivity and vegetation type. We also modeled the effects of nest box type (BP, SG, SP, KB), tree diameter, dieback score, log of the total number of stems, number of trees greater than 50 cm and within 50 m, number of hollow bearing trees within 50 m, distance to drainage line, topographic wetness index (TWI), lithology fertility rating, distance to closest major vegetation. The response variable for all analyses was the presence/absence of the species or species group of interest which we modeled using a binary logistic regression with a random effect for site. We used the glmer function from the lme4 package (Bates et al. 2014) to model the presence/absence of both the individual species and groups.

We used Akaike Information Criterion (AIC) to guide model selection on the logistic regression. We chose AIC over the Bayesian Information Criterion (BIC), at this preliminary stage, to allow the inclusion of more potential predictors in the model. Due to the more stringent inclusion criteria with larger sample sizes, BIC tends to favor simple models compared to AIC.

Due to the large number of potential predictor variables (14 plus an interaction), we employed the following two-part variable selection strategy. We used the package MuMIn (Barton 2014) to explore all possible subsets of the site level variables. We then retained the variables from the best fitting AIC model and carried them to the second stage of model selection. In the second stage, we then fitted all possible models from the next box-level variables while keeping the variables from the site-level stage in each of the models.

The final models were then fitted using the package MCMCglmm (Hadfield 2010). The MCMCglmm package fits the logistic regression model via Markov Chain Monte Carlo (MCMC) techniques and gives samples from the posterior distribution. We chose uninformative but proper priors for the fixed effects components and minimally informative but proper priors for the variance components. Specifically, we used multivariate normal priors for the regression parameters and inverse Wishart distributions for the variance components.

The logistic regression model parameters are summarized by the posterior mean, 95% credible intervals and Btail, which gives the fraction of the posterior distribution that is to the left(right) of zero if the posterior mean is greater(less) than zero. Small values of Btail indicate support for non-zero parameter values, that is, posterior distributions that are shifted away from zero. We report the parameters from the presence and conditional abundance components of the hurdle more on the log odds ratio and log scale respectively.

We also assessed the residuals from of the logistic regression models for evidence of nonlinearities over and above specified by our models using generalized additive models (Wood 2006). In all cases there was no evidence of non-linearities.

## **Results**

### ***General findings***

We recorded a high level of usage of the 150 nest boxes over the three years of our investigation (Table 1). We recorded 13 species of animals using nest boxes, including seven six species of native mammals: the Yellow-footed Antechinus (*Antechinus flavipes*; 2 detections), Sugar Glider (*Petaurus breviceps*; 2 detections), Common Brushtail Possum (*Trichosurus vulpecula*; 52 detections), Common Ringtail Possum (*Pseudocheirus peregrinus*; 8 detections), and Lesser long-eared Bat (*Nyctophilus geoffroyi*; 4 detections), and one introduced species – the Black Rat (*Rattus rattus*; 24 detections). The four bird

species detected using nest boxes were the Galah (*Eolophus roseicapillus*; 1 detection), Cockatiel (*Nymphicus hollandicus*; 1 detection), Eastern Rosella (*Platycercus eximius*; 23 detections) and the exotic European Starling (*Sturnus vulgaris*; 116 detections). The remaining two species of vertebrates detected were the Marbled Gecko (*Christinus marmoratus*; 2 detections) and Peron's Tree Frog (*Litoria peronii*; 6 detections). The Feral Honeybee (*Apis mellifera*; 71 detections) was the sole species of invertebrate that was identified to species level in this study.

### ***Key response variables influencing the occupancy of nest boxes***

We completed detailed statistical analyses of design variables and nest box, site and landscape-level covariates influencing six response variables; the occurrence of the Common Brushtail Possum, the presence of any mammal species, the occurrence of the exotic Common Starling, the presence of any bird species, the occurrence of the exotic Honeybee, and the presence of any species. Models showing all effects are summarized in Appendices 1 and 2.

### **Broad vegetation type differences – plantings versus remnants**

Our analyses revealed a lower probability of presence in a nest box within remnants (versus plantings) for two of the six response variables: any species ( $B_{tail} = 0.014$ ), and the Feral Honeybee ( $B_{tail} < 0.001$ ). The broad vegetation effect remained important only for the Feral Honeybee ( $B_{tail} = 0.047$ ) after fine scale variables were included in the final model (Figure 2A, Appendix 2).

### **Connected versus unconnected plantings and remnants**

Analyses of broad scale variables indicated that nest boxes in connected remnants and plantings were more likely to be occupied than isolated plantings and remnants by any mammal ( $B_{tail} = 0.029$ ) and the Common Brushtail Possum ( $B_{tail} < 0.001$ ). The reverse effect was observed for the Feral Honeybee ( $B_{tail} = 0.086$ ). These effects remained

unchanged after fine scale variables were included in the final model (Figure 2B).

Connectedness was not important in models based on either broad scale variables or the final models that included fine-scale variables for any bird response variable or for the Common Starling (Figure 2B).

We found no evidence of interaction effects between broad vegetation type and connectedness for any of the response variables we analysed.

#### Other effects

We found that nest box characteristics had an important effect on occupancy for the majority of response variables examined. The lowest rates of occupancy were in KB nest boxes for the Feral Honeybee (KB vs BP Btail = 0.018, KB vs SG Btail = 0.006), Common Starling (KB vs BP Btail <0.001, KB vs SG Btail <0.001), the presence of any bird species (KB vs BP Btail <0.001, KB vs SG Btail <0.001), and the presence of any species (KB vs BP Btail <0.001, KB vs SG Btail <0.001). The lowest rates of occupancy for the Common Brushtail Possum (SG vs BP Btail <0.001, SG vs KB Btail <0.001) and the presence of any mammal species (SG vs BP Btail <0.001, SG vs KB Btail = 0.004) were in SG nest boxes (Appendix 2).

Our analyses revealed that survey year effects were prominent in the final models for almost all of the responses variables we examined. The lowest probability of occurrence of the three species we analyzed (Common Brushtail Possum, Common Starling and Feral Honey Bees) and the three composite measures (any mammal, any bird, and any species) all were lowest in the first year of survey (summer 2010). The Common Brushtail Possum and any mammal experienced peak nest box occupancy in spring survey of 2011. By contrast, the greatest occupancy rate for the Common Starling, the Feral Honeybee and any bird species was in summer 2012 (Table S1, Appendices 1 and 2).

We found that the presence of any mammal (Btail < 0.001), and the Common Brushtail Possum (Btail = 0.002) were negatively associated with distance to a watercourse (Appendix

1; Figure 2C). Other variables featured in final models included: **(a)** A negative effect of distance to major block of native vegetation for any species ( $B_{tail} = 0.002$ ) and the Feral Honeybee ( $B_{tail} = 0.070$ ); **(b)** A positive association with the dieback score and the presence of any mammal ( $B_{tail} = 0.026$ ), and the presence of the Common Brushtail Possum ( $B_{tail} = 0.014$ ); **(c)** A positive association between the number of stems at a site and the presence of the Common Brushtail Possum ( $B_{tail} = 0.28$ ) and the presence of the Feral Honeybee ( $B_{tail} = 0.034$ ), and; **(d)** A negative association between the number of paddock trees and the presence of the Feral Honeybee ( $B_{tail} = 0.066$ ). Models showing these various effects are summarized in Appendix 2.

## Discussion

Large areas of highly modified agricultural land worldwide have been targeted for vegetation restoration as part of attempts to tackle problems such as land degradation and biodiversity loss (Ray Benayas et al. 2009; Lamb 2011; Menz et al. 2013). This is true in large parts of southern Australia where such problems are widely recognized (Hajkowicz 2009; Munro & Lindenmayer 2011). Time lags in the development of key structural attributes of the vegetation in restored areas potentially limits their value for some groups of animals such as hollow-dependent vertebrates (Cunningham et al. 2007; Vesk et al. 2008). In an attempt to counter this problem, the establishment of nest boxes within revegetated areas is a widely recommended management action in many parts of Australia (Durant et al. 2009; Goldingay et al. 2015). However, the effectiveness of nest box establishment in promoting biodiversity conservation within restored woodlands is poorly known, in part because the factors affecting occupancy and use have often not been documented in designed and implemented studies.

We addressed three key questions as part of this investigation. The answer to our first question: *Are there differences in nest box occupancy between woodland remnants and plantings?* – was generally no. Broad vegetation type effects were found for only two of the

six response variables we examined and then remained important only for the Feral Honeybee after fine scale variables were included in the final model. This result was unexpected as we postulated that rates of occupancy would be significantly higher in plantings than in remnants because the former broad vegetation type support fewer hollow-bearing trees. The reason for the paucity of broad vegetation effects remain unclear. It is possibly related to the fact that the woodlands in our study have been heavily altered and support significantly depleted numbers of hollow-bearing trees relative to unmodified woodlands (Gibbons et al. 2010). These woodland areas typically support fewer hollow-bearing trees per unit area than forests where most previous studies have been conducted and which show inverse relationships between nest box occupancy and the abundance of hollow trees (e.g. see Lindenmayer et al. 2009). Therefore, animals in woodland remnants (and plantings) may simply occupy nest boxes as they encounter them (Menkhorst 1984), resulting in a general lack of broad vegetation type differences as found in our study.

The second key question in our study was: *Are there differences in the occupancy of nest boxes among remnants and plantings that are physically connected to other areas of native vegetation and those which are isolated?* The answer to this question was that connectedness was generally important for nest box occupancy by mammals (any mammal, or the Common Brushtail Possum) but not for birds. This result was possibly associated with differences in mobility between arboreal and scansorial mammals and birds. Other studies of mammals have suggested that physical connections between areas of vegetation play an important role in patch occupancy in semi-cleared agricultural landscapes (e.g. van der Ree & Bennett 2003; van der Ree et al. 2004; Goldingay et al. 2013). Surprisingly, we identified a negative impact of connectedness on nest box occupancy by the Feral Honeybee. However, this effect disappeared once fine-scale variables had been incorporated in the final model,

suggesting that other factors associated with individual boxes (e.g. entrance size) and sites (e.g. stem density) outweigh the effects of physical connectedness for this species.

Our third question related to potential interaction effects between broad vegetation type and connectedness effects on nest box occupancy. No such effects were identified for any of the array of response variables subject to detailed analysis. To some extent, this result was unsurprising given that main effects for broad vegetation type were rare and connectedness effects were primarily confined to responses for mammals (see above).

Several tree and site-level covariates were important for some species and species groups. The use of nest boxes by the Common Brushtail Possum and mammals in general were significantly higher in sites closer to watercourses. This is likely the result of higher species abundance and/or the provision of high quality habitat in the mesic parts of the landscape, as has been shown for a number of arboreal and scansorial mammals (Soderquist & MacNally 2000; Crane et al. 2012). The use of nest boxes by the Common Brushtail Possum and mammals *per se*, also increased with elevated levels of ‘dieback’ in the tree to which a given nest box was attached. It is not clear if this effect is driven by a preference for trees of poor health or if it reflects some other (unmeasured) issues affecting tree health in areas selected by these species.

Our study revealed that nest boxes were used by a range of hollow-dependent fauna. However, the number of species which occupied boxes was ~15% of the total number of cavity-dependent vertebrates (excluding bats) that repeated survey work over the past decade has shown can occur in the temperate woodlands in the South West Slopes region, including the Junee area where this investigation was completed. We also note that almost none of the species recorded using nest boxes in our study were of conservation concern, in fact three of the most frequently recorded taxa were exotic. Cavity-dependent species of conservation concern such as the Superb Parrot, Brown Treecreeper, and Squirrel Glider were absent from

our surveys. This was despite two of the kinds of nest boxes deployed being specifically constructed for two of these species (the Squirrel Glider and the Superb Parrot). We note that while there are many records of the Superb Parrot and Brown Treecreeper from areas within 1-2 km of our study sites, there are none of the Squirrel Glider. Other researchers working elsewhere have recorded a high frequency of use of nest boxes by the Squirrel Glider (e.g. Beyer & Goldingay 2006; Goldingay et al. 2015). More tailored designs specifically to meet the requirements of particular animals of conservation concern may be appropriate if a management objective is to cater to the needs of animals of conservation concern. For example, a more tailored design for the Squirrel Glider would be a nest box with a rear-entry (Goldingay et al. 2015), although this would be of limited value in the particular area of our study given its apparent absence from the region. Lag effects in the use of nest boxes may be an additional or alternative explanation for the low rates of occupancy for some species of conservation concern. Our data show that the lowest probability of occupancy was in the first survey after establishment (2010) suggest that nest boxes may not have been discovered by animals. Delayed occupancy has been observed in other nest box studies and a longer term study in woodlands may be required to determine if greater rates of colonization by species of conservation concern occur over time. Finally, even in the absence of species of conservation concern, nest boxes can nevertheless be important for attracting other native animals like the Sugar Glider and Yellow-footed Antechinus which play key ecosystem service roles such as insect pest control, pollination and are prey to large owls (Goldingay et al. 1991; Lindenmayer 2002).

A key issue with the provision of nest boxes is the risk of creating additional nesting or sheltering habitat for pest species (Pell & Tiedemann 1997; Gibbons & Lindenmayer 2002), (but see Goldingay et al. 2015). Our data suggested that this problem is a legitimate concern in temperate woodland environments as three of the most commonly recorded individual



species were exotic species that are widely regarded as important pest animals – the Black Rat, Common Starling, and the Feral Honeybee. We suggest that one approach to limit nest box use by these species will be to ensure they have characteristics which make them unsuitable for pest species (Goldingay et al. 2015).

In summary, our study has shown that nest boxes can support the occupancy of some hollow-dependent species in plantings, but not at levels different to those observed in remnants of temperate eucalypt woodland. The connectedness of sites targeted for nest box establishment can have an important positive effect on the probability of occupancy and this appears to be an important consideration for attempts to improve the effectiveness of nest box programs. However, nest boxes in this study generally benefited already common species, including a number of pest species. In contrast, species of conservation concern were typically not recorded. A relatively small fraction of the overall total cavity-dependent fauna in our study region occupied nest boxes. This may have occurred because a limited range of nest box designs were employed, some plantings were not connected to other areas of native vegetation, and the relatively limited period that nest boxes had been established.

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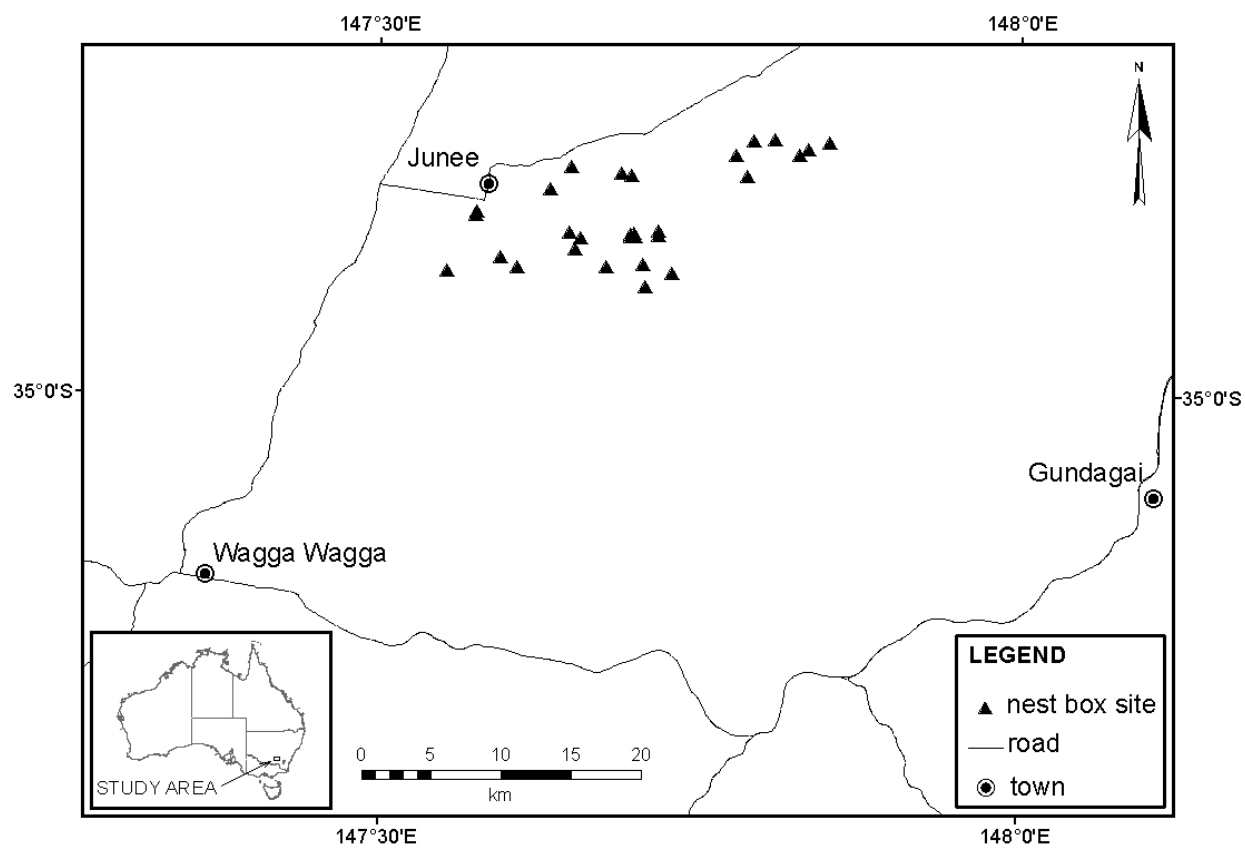
**Table 1.** Summary data showing the percentage occupancy of nest boxes by different species. Values in brackets are numbers of occupied boxes. Abbreviations are as follows: Tvu (*Trichosurus vulpecula*; Common Brushtail Possum); Rra (*Rattus rattus*, Black Rat); Ppe (*Pseudocheirus peregrinus*; Common Ringtail Possum); Pbr (*Petaurus breviceps*; Sugar Glider); Afl (*Antechinus flavipes*; Yellow-footed Antechinus); Nge (*Nyctophilus geoffroyii*; Lesser Long-eared Bat); Svu (*Sturnus vulgaris*; Common Starling); Pex (*Platycercus eximus*; Eastern Rosella); Ero (*Eolophus eximius*; Galah); Nho (*Nymphicus hollandicus*; Cockatiel); Lper (*Litoria peronii*; Peron's Tree Frog); Cma (*Christinus marmoratus*; Marbled Gecko) and Ame (*Apis mellifera*; Feral Honeybee). Exotic species are denoted by a star (\*)

Nest box type	Percentage of boxes used													No evidence of use
	Tvu	Rra*	Ppe	Pbr	Afl	Nge	Svu*	Pex	Ero	Nho	Lper	Cma	Ame*	
Brushtail Possum box (44)	36% (16)	9% (4)	9% (4)	2% (1)	2% (1)	0	43% (19)	11% (5)	0	0	7% (3)	2% (1)	31% (14)	2% (1)
Kookaburra box (16)	38% (6)	13% (2)	6% (1)	0	0	0	13% (2)	0	0	0	0		19% (3)	13% (2)
Squirrel Glider box (60)	5% (3)	18% (11)	2% (1)	2% (1)	7% (4)	5% (3)	65% (39)	8% (5)	2% (1)	2% (1)	5% (3)	2% (1)	33% (20)	3% (2)
Superb Parrot box (30)	33% (10)	13% (4)	7% (2)	0	0	0	43% (13)	23% (6)	0	0	0	0	40% (12)	0

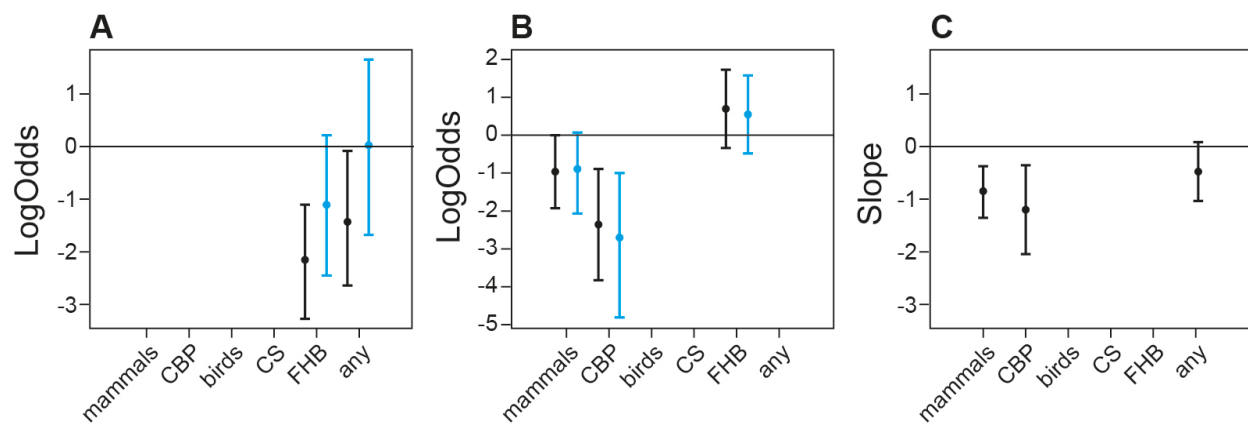
**Figure 1.** The location of the study area and field sites (16 plantings and 14 remnants) where nest boxes were established and checked four times between 2010 and 2012.

**Figure 2.** Nest box occupancy for species groups and individual species (with associated  $\pm 95\%$  credible intervals). Black credible intervals correspond to the final models constructed from the broad scale variables only, whereas, the blue intervals correspond to the final model after inclusion of the fine scale variables. Absence of credible intervals indicate that a given variable vegetation was not important in the broad scale analysis. **A.** Nest box occupancy in relation to broad vegetation type (remnants versus plantings). The y-axis is on the log-odds scale:  $\log(\text{odds of Remnant} / \text{odds Planting})$ , values greater than 0 indicate a preference for remnant patches, whereas values less than 0 indicate a preference for plantings. **B.** Nest box occupancy in relation to connected and unconnected remnants and plantings. Absence of credible intervals indicate that connectivity was not important in the broad scale analysis. The y-axis is on the log-odds scale:  $\log(\text{odds of Isolated} / \text{odds of Connected})$ , values greater than 0 indicate a preference for isolated patches, whereas values less than 0 indicate a preference for connected patches. **C.** Nest box occupancy in relation to the distance to drainage line. An absence of credible intervals indicate that distance to drainage line was not important in the fine scale analysis. The y-axis corresponds to the linear slope of distance to drainage lines, values less than 0 indicate a negative association between distance from drainage line and presence of the indicated species or species group. Abbreviations are as follows: CBP (Common Brushtail Possum), CS (Common Starling), FHB (Feral Honeybee), Any (any species).



29 **Figure 1**

30

31 **Figure 2**

32

## SUPPLEMENTARY TABLE AND APPENDICES

**Table S1: Dimensions of the four different types of nest boxes deployed in this study**

<b>Box type</b>	<b>Height</b>	<b>Depth</b>	<b>Width</b>	<b>Hole size</b>	<b>Bat</b>
	<b>(mm)</b>	<b>(mm)</b>	<b>(mm)</b>	<b>(mm)</b>	<b>chamber</b>
Common Brushtail	500	350	360	80	no
Possum Box					
Superb Parrot Box	550	250	260	80	no
Squirrel Glider Box	500	230	240	45	yes
Kookaburra Box	250	260	550	90	yes

## Appendix 1: Broad scale variables

### Appendix 1A: Presence of any mammal species – Posterior summary of Random effects

logistic regression model. Abbreviations Sm and S correspond to summer and spring, respectively.

Fixed Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI	Btail
Intercept (SurveyOcc: 2010.S, Connectivity: Connected)	-3.199	-2.233	-4.148	<0.001
SurveyOcc 2011.S	2.133	3.014	1.219	<0.001
SurveyOcc 2011.Sm	1.073	1.984	0.055	0.012
SurveyOcc 2012.S	1.630	2.519	0.719	<0.001
Connectivity Isolated	-0.937	0.007	-1.925	0.029
<b>Additional Comparisons</b>				
SurveyOcc: 2011.S vs 2011.Sm	1.060	0.332	1.748	0.002
SurveyOcc: 2011.S vs 2012.S	0.503	-0.154	1.163	0.068
SurveyOcc: 2011.Sm vs 2012.S	-0.557	-1.317	0.212	0.078

Random Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI
SiteCode RE	1.221	0.452	2.144
Observation Level RE	0.574	0.184	1.121

**Appendix 1B:** Presence of Common Brushtail Possum – Posterior summary of Random effects logistic regression model. Abbreviations Sm and S correspond to summer and spring, respectively.

Fixed Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI	Btail
Intercept (SurveyOcc: 2010.S, NestBoxType: BP, Connectivity: Connected)	-3.104	-1.982	-4.172	<0.001
SurveyOcc 2011.S	1.241	2.258	0.293	0.008
SurveyOcc 2011.Sm	0.675	1.576	-0.394	0.098
SurveyOcc 2012.S	0.449	1.54	-0.577	0.188
Connectivity Isolated	-2.357	-0.877	-3.829	<0.001
<b>Additional Comparisons</b>				
SurveyOcc: 2011.S vs 2011.Sm	0.566	-0.348	1.48	0.113
SurveyOcc: 2011.S vs 2012.S	0.792	-0.144	1.71	0.052
SurveyOcc: 2011.Sm vs 2012.S	0.226	-0.732	1.173	0.318

Random Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI
SiteCode RE	1.794	0.586	3.257
Observation Level RE	0.575	0.204	1.068

**Appendix 1C:** Presence of any bird species – Posterior summary of Random effects logistic regression model. Abbreviations Sm and S correspond to summer and spring, respectively.

Fixed Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI	Btail
Intercept (SurveyOcc: 2010.S)	-3.870	-2.868	-4.891	<0.001
SurveyOcc 2011.S	2.575	3.437	1.629	<0.001

SurveyOcc 2011.Sm	2.785	3.716	1.872	<0.001
SurveyOcc 2012.S	2.957	3.913	2.079	<0.001
<b>Additional Comparisons</b>				
SurveyOcc: 2011.S vs 2011.Sm	-0.209	-0.871	0.444	0.268
SurveyOcc: 2011.S vs 2012.S	-0.381	-0.998	0.275	0.117
SurveyOcc: 2011.Sm vs 2012.S	-0.172	-0.811	0.433	0.293

Random Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI
SiteCode RE	2.018	0.815	3.487
Observation Level RE	0.547	0.177	1.012

#### **Appendix 1D:** Presence of Common Starling – Posterior summary of Random effects

logistic regression model. Abbreviations Sm and S correspond to summer and spring, respectively.

Fixed Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI	Btail
Intercept (SurveyOcc: 2010.S)	-4.018	-2.986	-5.093	<0.001
SurveyOcc 2011.S	2.547	3.577	1.594	<0.001
SurveyOcc 2011.Sm	2.327	3.448	1.411	<0.001
SurveyOcc 2012.S	2.859	3.816	1.791	<0.001
<b>Additional Comparisons</b>				
SurveyOcc: 2011.S vs 2011.Sm	0.220	-0.438	0.903	0.267
SurveyOcc: 2011.S vs 2012.S	-0.312	-0.965	0.374	0.174
SurveyOcc: 2011.Sm vs 2012.S	-0.532	-1.172	0.115	0.056

Random Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI
SiteCode RE	1.871	0.768	3.181
Observation Level RE	0.522	0.197	0.986

**Appendix 1E:** Presence of Feral Honeybees – Posterior summary of Random effects logistic regression model. Abbreviations Sm and S correspond to summer and spring, respectively.

Fixed Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI	Btail
Intercept (SurveyOcc: 2010.S, VegetationType: Planting)	-3.743	-1.636	-6.021	<0.001
SurveyOcc 2011.S	2.734	4.273	1.215	<0.001
SurveyOcc 2011.Sm	2.642	4.127	1.213	<0.001
SurveyOcc 2012.S	4.399	5.948	2.940	<0.001
Connectivity Isolated	0.702	1.731	-0.333	0.086
VegetationType Remnant	-2.168	-1.103	-3.269	<0.001
No. of paddock trees in 500m	-0.990	0.032	-2.132	0.030
<b>Additional Comparisons</b>				
SurveyOcc: 2011.S vs 2011.Sm	0.092	-0.818	0.931	0.416
SurveyOcc: 2011.S vs 2012.S	-1.665	-2.483	-0.894	<0.001
SurveyOcc: 2011.Sm vs 2012.S	-1.757	-2.608	-1.012	<0.001

Random Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI
SiteCode RE	0.847	0.283	1.557
Observation Level RE	0.534	0.195	1.004

**Appendix 1F:** Presence of any species – Posterior summary of Random effects logistic regression model. Abbreviations Sm and S correspond to summer and spring, respectively.

Fixed Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI	Btail
Intercept (SurveyOcc: 2010.S, Vegetation Type: Planting)	-1.935	-0.836	-2.916	<0.001
SurveyOcc 2011.S	3.225	4.038	2.436	<0.001
SurveyOcc 2011.Sm	2.748	3.568	2.080	<0.001
SurveyOcc 2012.S	4.736	5.666	3.781	<0.001
VegetationType Remnant	-1.407	-0.091	-2.639	0.014
<b>Additional Comparisons</b>				
SurveyOcc: 2011.S vs 2011.Sm	0.477	-0.118	1.098	0.066
SurveyOcc: 2011.S vs 2012.S	-1.511	-2.345	-0.726	<0.001
SurveyOcc: 2011.Sm vs 2012.S	-1.988	-2.793	-1.25	<0.001

Random Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI
SiteCode RE	2.920	1.154	4.930
Observation Level RE	0.511	0.188	1.005

## Appendix 2. Broad + fine scale variables

(Broad scale variables remain in the model and the model selection is done on which fine scale variables are important)

**Appendix 2A:** Presence of any mammal species – Posterior summary of Random effects logistic regression model. Abbreviations Sm and S correspond to summer and spring, respectively.

Fixed Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI	Btail
Intercept (SurveyOcc: 2010.S, NestBoxType: BP, Connectivity: Connected)	-3.356	-2.262	-4.584	<0.001
SurveyOcc 2011.S	2.374	3.382	1.348	<0.001
SurveyOcc 2011.Sm	1.171	2.200	0.117	0.010
SurveyOcc 2012.S	1.779	2.821	0.890	<0.001
Connectivity Isolated	-0.922	0.035	-2.065	0.036
NestBoxType KB	-0.045	0.794	-0.964	0.475
NestBoxType SG	-1.426	-0.732	-2.085	<0.001
Dieback Score	0.320	0.636	-0.029	0.026
Distance to drainage line	-0.828	-0.354	-1.349	<0.001
Tree Diameter	-0.506	-0.100	-0.915	0.009
<b>Additional Comparisons</b>				
SurveyOcc: 2011.S vs 2011.Sm	1.203	0.387	2.015	0.001
SurveyOcc: 2011.S vs 2012.S	0.595	-0.109	1.301	0.052
SurveyOcc: 2011.Sm vs 2012.S	-0.607	-1.489	0.194	0.072
NestBoxType: KB vs SG	1.381	0.434	2.335	0.004



Random Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI
SiteCode RE	1.162	0.404	2.180
Observation Level RE	0.641	0.194	1.344

**Appendix 2B:** Presence of Common Brushtail Possum – Posterior summary of Random effects logistic regression model. Abbreviations Sm and S correspond to summer and spring, respectively.

Fixed Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI	Btail
Intercept (SurveyOcc: 2010.S, NestBoxType: BP, Connectivity: Connected)	-4.619	-2.703	-6.565	<0.001
SurveyOcc 2011.S	1.710	2.961	0.609	0.002
SurveyOcc 2011.Sm	0.911	2.110	-0.244	0.068
SurveyOcc 2012.S	0.492	1.775	-0.616	0.196
Connectivity Isolated	-2.665	-1.024	-4.811	0.002
NestBoxType KB	0.438	1.477	-0.666	0.212
NestBoxType SG	-3.557	-2.189	-5.091	<0.001
Dieback Score	0.565	1.034	0.005	0.014
Distance to drainage line	-1.224	-0.347	-2.044	0.002
logStemsP1	0.928	1.886	-0.029	0.028
<b>Additional Comparisons</b>				
SurveyOcc: 2011.S vs 2011.Sm	0.799	-0.304	1.921	0.077
SurveyOcc: 2011.S vs 2012.S	1.218	0.130	2.321	0.018

SurveyOcc: 2011.Sm vs 2012.S	0.419	-0.713	1.536	0.240
NestBoxType: KB vs SG	3.996	2.352	5.803	<0.001

Random Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI
SiteCode RE	2.686	0.748	5.259
Observation Level RE	0.570	0.193	1.122

**Appendix 2C:** Presence of any bird species – Posterior summary of Random effects logistic regression model. Abbreviations Sm and S correspond to summer and spring, respectively.

Fixed Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI	Btail
Intercept (SurveyOcc: 2010.S, NestBoxType: BP)	-4.553	-3.411	-5.735	<0.001
SurveyOcc 2011.S	2.917	3.926	1.912	<0.001
SurveyOcc 2011.Sm	3.158	4.215	2.141	<0.001
SurveyOcc 2012.S	3.379	4.429	2.408	<0.001
NestBoxType KB	-3.300	-1.650	-4.831	<0.001
NestBoxType SG	0.964	1.507	0.416	<0.001
Tree Diameter	0.313	0.631	-0.072	0.039
<b>Additional Comparisons</b>				
SurveyOcc: 2011.S vs 2011.Sm	-0.240	-0.906	0.446	0.248
SurveyOcc: 2011.S vs 2012.S	-0.462	-1.105	0.180	0.084
SurveyOcc: 2011.Sm vs 2012.S	-0.221	-0.892	0.458	0.259
NestBoxType: KB vs SG	-4.263	-6.046	-2.715	<0.001

Random Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI
SiteCode RE	2.744	1.162	4.891
Observation Level RE	0.529	0.157	0.998

**Appendix 2D:** Presence of Common Starling – Posterior summary of Random effects

logistic regression model. Abbreviations Sm and S correspond to summer and spring, respectively.

Fixed Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI	Btail
Intercept (SurveyOcc: 2010.S, NestBoxType: BP)	-4.813	-3.592	-5.989	<0.001
SurveyOcc 2011.S	2.823	3.831	1.796	<0.001
SurveyOcc 2011.Sm	2.584	3.678	1.577	<0.001
SurveyOcc 2012.S	3.222	4.247	2.167	<0.001
NestBoxType KB	-2.587	-1.038	-4.137	<0.001
NestBoxType SG	1.226	1.777	0.625	<0.001
<b>Additional Comparisons</b>				
SurveyOcc: 2011.S vs 2011.Sm	0.239	-0.471	0.962	0.260
SurveyOcc: 2011.S vs 2012.S	-0.399	-1.092	0.299	0.127
SurveyOcc: 2011.Sm vs 2012.S	-0.638	-1.355	0.064	0.040
NestBoxType: KB vs SG	-3.813	-5.674	-2.374	<0.001

Random Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI
SiteCode RE	2.424	0.933	4.129
Observation Level RE	0.534	0.197	1.015

**Appendix 2E:** Presence of Feral Honeybees – Posterior summary of Random effects logistic regression model. Abbreviations Sm and S correspond to summer and spring, respectively.

Fixed Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI	Btail
Intercept (SurveyOcc: 2010.S, NestBoxType: BP, VegetationType: Planting)	-5.776	-3.237	-8.305	<0.001
SurveyOcc 2011.S	2.966	4.785	1.379	<0.001
SurveyOcc 2011.Sm	2.831	4.617	1.264	<0.001
SurveyOcc 2012.S	4.771	6.447	3.085	<0.001
Connectivity Isolated	0.582	1.577	-0.439	0.122
VegetationType Remnant	-1.109	0.224	-2.451	0.047
NestBoxType KB	-1.415	-0.159	-3.021	0.018
NestBoxType SG	0.362	1.067	-0.280	0.146
No. of paddock trees in 500m	-0.710	0.246	-1.699	0.066
logStemsP1	0.760	1.609	-0.051	0.034
Distance to closest major veg	0.470	1.091	-0.159	0.070
<b>Additional Comparisons</b>				
SurveyOcc: 2011.S vs 2011.Sm	0.135	-0.818	1.126	0.392
SurveyOcc: 2011.S vs 2012.S	-1.806	-2.654	-0.983	<0.001

SurveyOcc: 2011.Sm vs 2012.S	-1.941	-2.863	-1.116	<0.001
NestBoxType: KB vs SG	-1.777	-3.359	-0.405	0.006

Random Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI
SiteCode RE	0.682	0.251	1.329
Observation Level RE	0.649	0.197	1.351

**Appendix 2F:** Presence of any species – Posterior summary of Random effects logistic regression model. Abbreviations Sm and S correspond to summer and spring, respectively.

Fixed Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI	Btail
Intercept (SurveyOcc: 2010.S, NestBoxType: BP, Vegetation Type: Planting)	-2.837	-1.603	-4.006	<0.001
SurveyOcc 2011.S	3.550	4.405	2.790	<0.001
SurveyOcc 2011.Sm	3.012	3.839	2.252	<0.001
SurveyOcc 2012.S	5.290	6.290	4.274	<0.001
VegetationType Remnant	0.022	1.654	-1.667	0.494
NestBoxType KB	-2.129	-1.204	-3.047	<0.001
NestBoxType SG	0.526	1.081	-0.065	0.037
Distance to drainage line	-0.463	0.103	-1.027	0.054
Distance to closest major veg	1.271	2.256	0.440	0.002
<b>Additional Comparisons</b>				
SurveyOcc: 2011.S vs 2011.Sm	0.538	-0.133	1.224	0.064

SurveyOcc: 2011.S vs 2012.S	-1.739	-2.583	-0.929	<0.001
SurveyOcc: 2011.Sm vs 2012.S	-2.278	-3.174	-1.450	<0.001
NestBoxType: KB vs SG	-2.654	-3.639	-1.718	<0.001

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Random Effects:

Parameter	Posterior mean	l-95% CI	u-95% CI
SiteCode RE	3.025	1.256	5.151
Observation Level RE	0.532	0.208	1.001

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